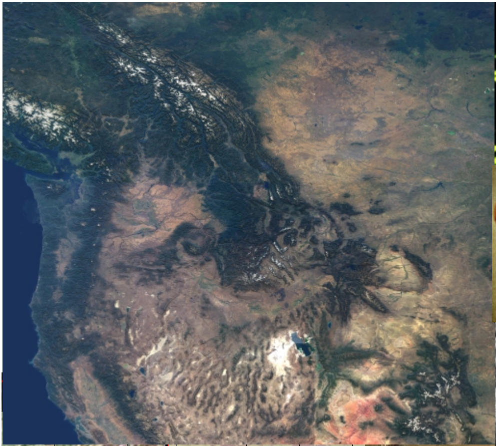
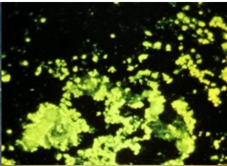
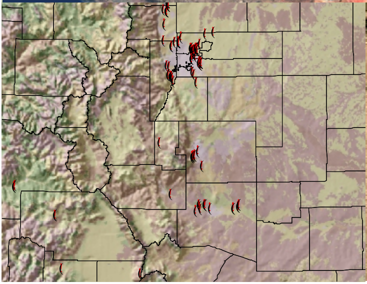
Remote Sensing for Public Health

New Tools for Public Health Practice

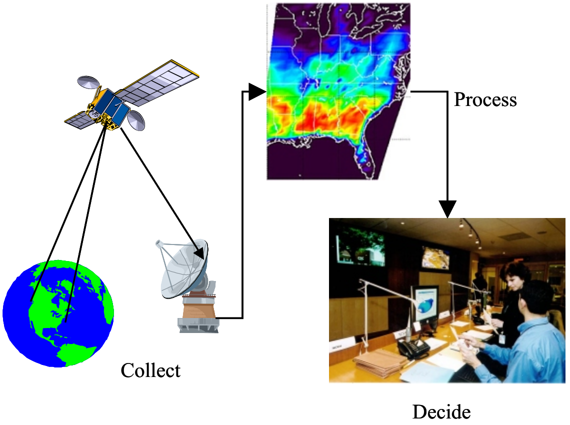




For centuries, public health and medical efforts have focused on disease prevention, surveillance, treatment, and eradication.

phil.cdc.gov

Now there are tools available to enable significant improvements in disease surveillance and public health practice. Imagine a future where public health professionals have a complete understanding of links between health of the environment and people. In this future, more precise and sensitive models predict infectious disease outbreaks and a public health system integrated by high-tech communications launches a response before the disease or environmental health concern becomes wide spread. These public health professionals are able to more completely understand disease ecology, track the fate of toxins, identify harmful exposures, and provide critical health information to the public with great speed.



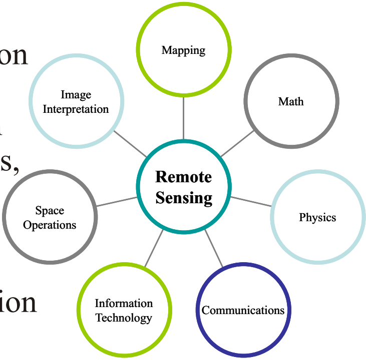
That future may not be far away. The National Aeronautics and Space Administration (NASA) Earth Science Enterprise, Public Health Application Program, is partnering with the public health community to tackle age-old problems with 21st century science and technology.

A new tool in the arsenal against disease is remote sensing. NASA is a world leader in development, deployment, and exploitation of remote sensing technologies. NASA's advanced satellites, sensors, communication networks, and computing capabilities, combined with the increasing use of geographic information systems hold great promise for advancements in public health practice.

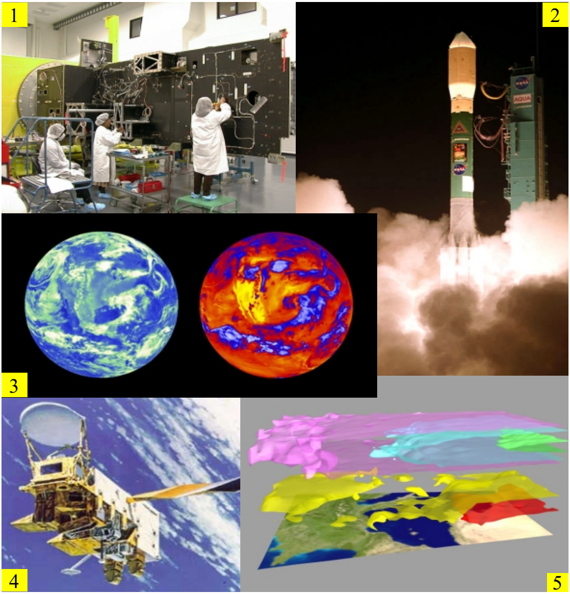
What is Remote Sensing?

"Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation." (Lillesand and Kiefer, 2000)

Remote sensing builds on the advances of many diverse disciplines such as Physics, Mathematics, Space Operations, Image Interpretation, Communications, Mapping, and Information Technology.



The human eye, a camera, an X-ray, and weather radar are all examples of remote sensing devices. In Earth sciences, we are often concerned with the collection of information over large areas. This can be accomplished by mounting a remote sensing device on an airplane or satellite.



The Aqua satellite: 1) Construction, 2) Launch, 3) Imagery, 4) On orbit, 5) Product (3-D atmospheric map).
aqua.gsfc.nasa.gov

Airborne and spaceborne Earth science findings are verified and supplemented by ground-based *in situ* measurements. These collective data are developed into useful information products such as aerosol, precipitation, and temperature maps that scientists use to better understand complex Earth processes.

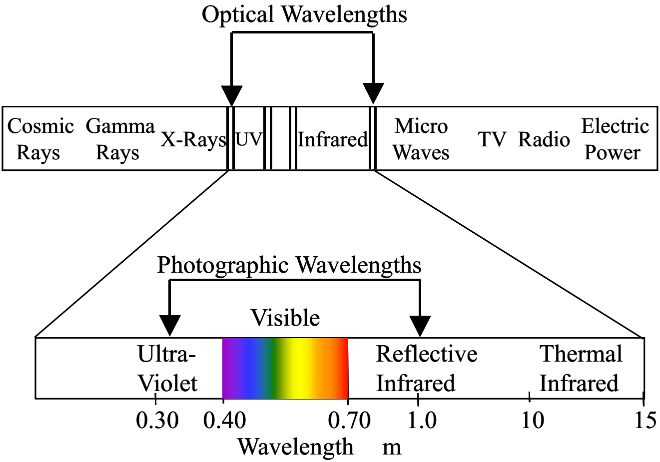
What Does Remote Sensing Measure?

There are many different types of remote sensing instruments that can detect and measure different types of energy. Acoustic sensors detect sound wave energy and electro-optical sensors detect electromagnetic (EM) energy. This booklet is restricted to discussion of Earth observation sensors that record EM energy. EM energy can be described with the general equation:

$$c =$$

Where c is the speed of light ($3 \text{ x}10^8$ m/s), is the wavelength of energy, and is the frequency of the EM wave. Variations in EM wavelengths or frequencies can be plotted on a continuum called the EM spectrum. EM energy on the low end of the spectrum has short wavelengths and a high frequency (e.g., cosmic rays).

The high end of the spectrum has long wavelengths and low frequencies (e.g., radio waves).

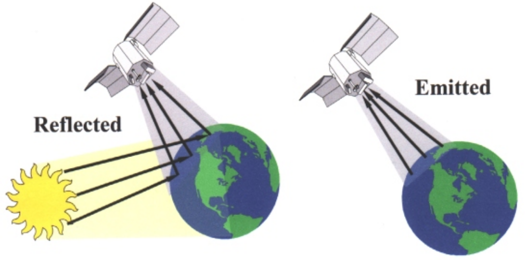


Any given remote sensing device typically measures discrete portions of the spectrum (spectral bands). For example, our eyes are sensitive to the "visible" portion of the spectrum covering the wavelength range of 0.4 to 0.7 micrometers - blue, green, and red light. Man-made sensors can be designed to detect energy in other portions of the spectrum.

Earth observation sensors record **reflected** and **emitted** electromagnetic energy.

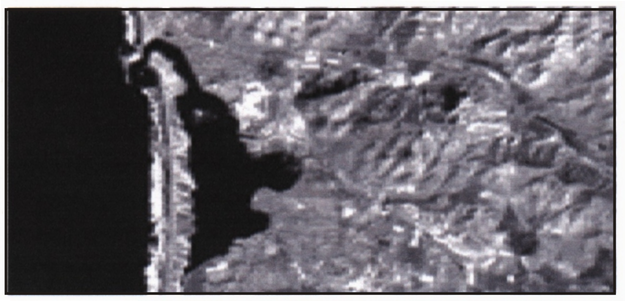
Reflected energy is a result of an object's interaction with energy from another source. The energy may have originated from the Sun, a laser, or a microwave device (radar).

All matter with a temperature above absolute zero emits its own electromagnetic energy. Earth surface features, the atmosphere, and clouds are all sources of energy that can be recorded by instruments. These instruments are often referred to as thermal remote sensors.



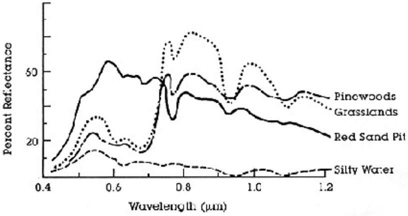
Different features on the Earth's surface reflect, absorb, or emit energy differently. Vegetation <u>reflects</u> near infrared (NIR) radiation strongly.

Water absorbs NIR radiation. For example, the vegetation in this Landsat NIR image is reflective (light gray to white) and the water is absorptive (black).



Viewing water and vegetation with NIR bands.
rst.gsfc.nasa.gov/Sect1/Sect1_3.html

Different Earth surface features and the atmosphere also emit energy and these differences can be measured with thermal sensors. These spectral differences define an object's spectral response curve or "signature," which forms the basis for allowing us to derive useful information from remote sensing.



Remote Sensing: An End-to-End Process

Remote sensing is an “end-to-end” process that may be described with the following components:

* A phenomenon of interest

* Energy source (e.g., the Sun)

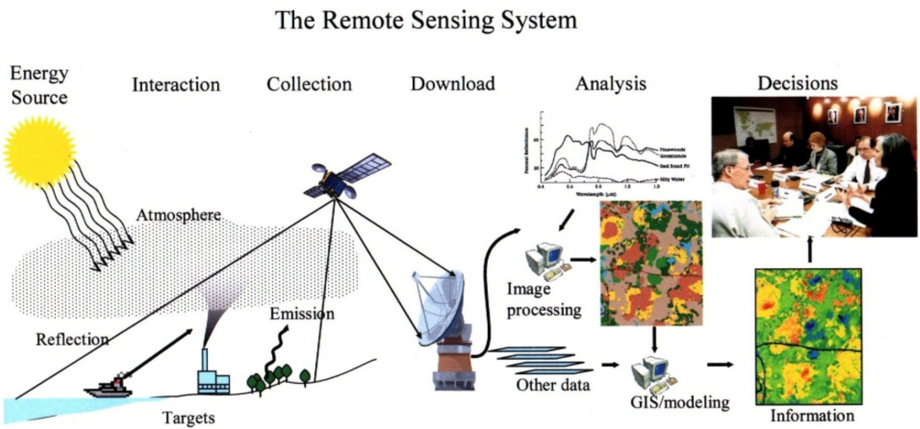
* Energy interactions (e.g., with the atmosphere or the surface)

* A sensor system

* An image processing system

* An end user of the data and information

An image processing system usually consists of a trained analyst that makes use of computer programs to analyze the data from the sensor system. Output from the image processing system consists of information that can be analyzed alone or used in conjunction with other data to help the user make more informed decisions.



In the remote sensing process, energy is either reflected or emitted from the target. That energy has to pass through the atmosphere (once if emitted, twice if reflected) before it is collected by the sensor. After the satellite collects the data and delivers it to the ground station, it is processed and analyzed to generate products that can be used in making decisions.

Collecting, Processing, and Archiving Data

NASA's Earth Science Enterprise is dedicated to understanding and protecting our home planet. We have come to understand that the only way to understand Earth's climate and manage its precious natural resources is to look at the planet as a single, integrated system of continents, oceans, atmosphere, ice, and life.

NASA and its partner agencies continuously observe Earth from space, from different vantage points and in a variety of wavelengths, to better understand the behavior and interactions of the planet's complex systems and processes.

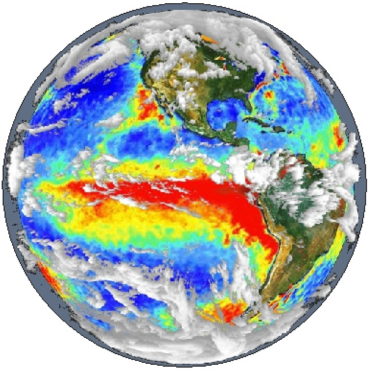
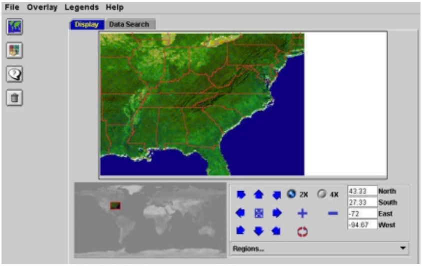


Image by R.B. Husar, Washington University; the land layer from the SeaWiFS Project; fire maps from the European Space Agency; the sea surface temperature from the Naval Oceanographic Office's Visualization Laboratory; and cloud layer from SSEC, U. of Wisconsin.

NASA sensors collect an unprecedented amount of data. In fact, the data volume is measured in terms of petabytes (a billion megabytes). NASA's capabilities include data processing and supercomputing, data product development, data archiving, and the development of data information systems.

NASA data and data products are stored at several Distributed Active Archive Centers (DAACs). These centers support the interactive and interoperable retrieval and distribution of data products through the World Wide Web.



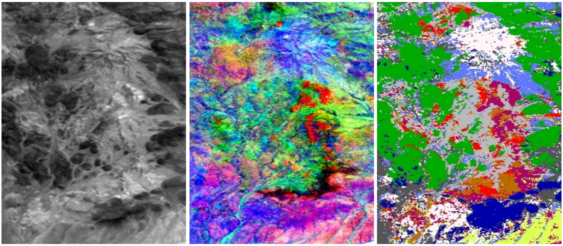
GSFC Earth Sciences, Data and Information Services Center

Software used to manipulate data continues to improve in functionality and ease of use. Data from many NASA satellites are easily input into the most popular commercial software packages.

Analysis and Application

Public health applications use remotely sensed data of the Earth's surface as input to disease surveillance and environmental health tracking systems. Some of these data are processed into imagery that is then analyzed and interpreted.

Digital image processing techniques turn raw data into useful products. Algorithms or equations are applied to each pixel of data. The results are stored as a new digital image such as a land cover classification map. An experienced image analyst assesses the results and decides if a different algorithm should be applied.



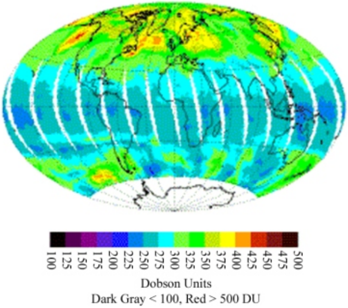
a. b. c.

In this series, principal component analysis is used on a Landsat image (a) to transform it into a product where different minerals on the ground can be delineated (b). In the final image (c) a supervised classification technique is used to further refine the data. rst.gsfc.nasa.gov/Sect1.

Over the past few decades, many algorithms have been developed to derive surface and atmospheric information for specific satellites.

Other potentially useful information such as rainfall density and ozone concentrations can also be measured and displayed.

NASA's Tropical Rainfall Measuring Mission (TRMM) and Total Ozone Mapping Spectrometer (TOMS) are examples of satellites providing these types of data.



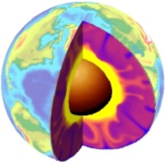
TOMS Composite Image

Existing and planned NASA satellites and sensors measure vegetation cover and biomass, temperature and humidity, and atmospheric chemistry. These measurements may prove useful for enhanced disease and environmental health surveillance. These space-based observations could provide valuable direct or indirect risk factor information that cannot be obtained from any other vantage.

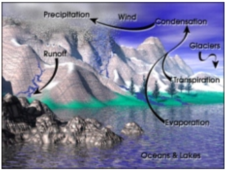
Modeling

Computer simulation modeling is used extensively to aid the measurement of complex systems and to predict the consequences of natural or human-induced events such as increases in CO_2 in the atmosphere. For example, scientists use remotely sensed data as input to models to improve understanding of global climate change and its potential effects on Earth system processes such as the global water and carbon cycles. These forcing effects may directly impact human health across the globe.

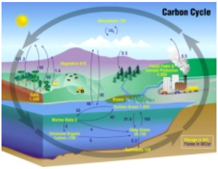
Solid Earth



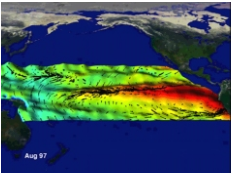
Water & Energy



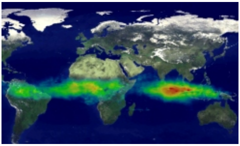
Carbon



Weather/Climate



Chemistry



However, the user or developer of a model must understand the physical principles embedded in the model and the model's limitations. After all, models are inherently incomplete since they are only 'abstractions' of current human knowledge and understanding of a system.

We have a fair understanding of the information remote sensing can provide, an increasing volume of spatial and temporal information, and a maturing class of Earth systems models that require remotely sensed data as input.

Our understanding of complex Earth system processes will continue to increase with the improved collection and analysis of remotely sensed data. Earth system models will also continue to improve in terms of sensitivity and precision.

As model improvements are made, they could potentially be used to help monitor and predict environmental conditions that are linked to health risks or adverse health outcomes.

Barriers and Limitations

Remotely sensed data is unmatched in spatial and temporal detail. However, we must recognize the limitations associated with remote sensing. These limitations may be described in terms of a sensor system's spatial, spectral, temporal, and radiometric resolutions. The laws of physics put constraints on a sensor system's ability to detect and resolve.

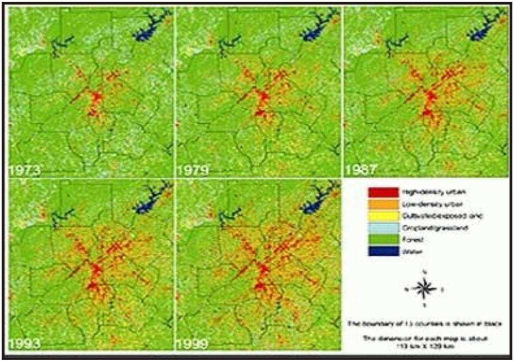
Spatial: Refers to a sensor's ability to detect and resolve targets of different size. It is usually related to pixel size.

Satellite Image 30-meter Pixels — Aerial Photograph 1-meter Pixels
www.csc.noaa.gov/products/sccoasts/html/rsdetail.htm

Spectral: Refers to a sensor's ability to detect and resolve different wavelengths. Decades of research have provided insight into which specific portions of the EM spectrum are important for detecting or analyzing certain features and phenomena.

For example, vegetation vigor is best observed in the near infrared, while water clarity is best observed in the blue region of the spectrum.

Temporal: Refers to a sensor's ability to revisit the same target area. For example, weather changes constantly and must be observed frequently. Urban growth is more gradual and requires less frequent revisits. The sensor's revisit capability must always be considered and matched to the phenomena of interest.



26 years of urban growth in the Atlanta area
rst.gsfc.nasa.gov/Sect4/

Radiometric: Refers to a senor's ability to detect and resolve differences in energy.

Future Directions & Opportunities

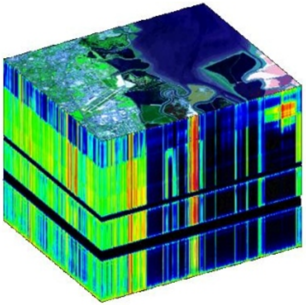
Remote sensing and related technologies continue to be improved and developed. As of this writing there are some 80 satellite platforms planned for Earth observation over the next seven years by the United States and the International community. (Beck, et al, 2000)

This is a sample of Earth observing satellites NASA has planned or already in orbit.

This growth in observational capability, combined with continual advancements in computing and communications, and innovative technology developments could provide the public health practice community with powerful tools and new opportunities for significantly advancing the state of the nation's health.

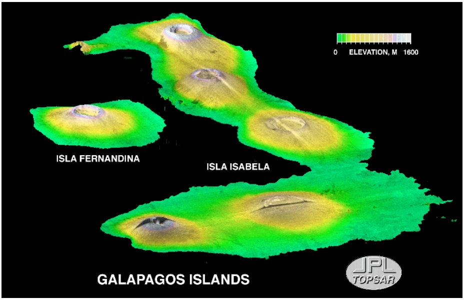
This booklet has only begun to describe the potential uses of remote sensing for public health applications. NASA is developing and evolving many other technologies that will make remote sensing even more useful. For example:

Hyperspectral imagers detect energy in hundreds to thousands of narrow wavelength bands. This increased resolution allows detection of subtle differences in features, objects, or the environment.



This "hypercube" represents the hundreds of layers (spectral bands) that are available with hyperspectral imagers. Various layers highlight different characteristics of the environment.

Synthetic Aperture Radar (SAR) is an active sensor that provides its own energy source to detect features and phenomena. SAR is able to penetrate or “see” through clouds, vegetation, or even soil surface in day or night conditions. SAR is also very good at detecting fine terrain detail as shown in this image of the Galapagos Islands.



southport/jpl.nasa.gov/

Lasers can be used to monitor gases, such as CO_2, by measuring a molecule’s unique absorption properties. Differential absorption lidar (DIAL) sensors have not yet flown on orbit.

Satellite platform advances, such as improvements in power management, on-board data processing, and communication will better support increasingly complex instrument payloads.

These technologies are just a few of the new and exciting developments on the horizon that will soon be available to the public health community.

For more information:
NASA's Earth Science Enterprise
www.earth.nasa.gov/

NASA's Remote Sensing Tutorial
rst.gsfc.nasa.gov/

Selected References and Further Reading

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About the Cover

Plague persists throughout the Southwest U.S. and is transmitted to humans by fleas that are infected with the bacteria. Rodents, like the one pictured, are a disease host and contribute to the transmission cycle. The satellite image of the Southwest was collected by the Multi-angle Imaging SpectroRadiometer (MISR) sensor aboard NASA's Terra satellite. The upper right image is a stain of the bacteria. The map at lower left is an example of how the CDC uses remotely sensed data and geographic information systems to monitor plague-positive prairie dog colonies.

Cover Photo Credits

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* CDC NCID: Dr. Ken Gage
* NASA: photojournal.jpl.nasa.gov/catalog/PIA04330

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